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EVALUATION OF TWO METHODS OF PROMPTING DRIVERS TO USE SPECIFIC EXITS ON CONFLICTS BETWEEN VEHICLES AT THE CRITICAL EXIT

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The Florida Department of Transportation used a series of changeable-message signs that functioned as freeway guide signs to divert traffic to Universal Theme Park via one of two eastbound exits based on traffic congestion at the first of the two exits. An examination of crashes along the entire route indicated a statistically significant increase in crashes at the first eastbound exit following the actuation of the system. Furthermore, all of the crashes occurred in close proximity to the exit gore (the crosshatched area at exits that drivers are not supposed to enter or traverse) at the first exit. In Experiment 1, behavioral data were collected using an alternating treatments design. These data revealed that reassigning the exit signs was effective in producing a change in the percentage of drivers using each of the two exits. These data also showed that the reassignment of the theme park exit was associated with an increase in the percentage of motor vehicle conflicts that consisted of vehicles cutting across the exit gore. An analysis revealed that the method used for switching the designated or active theme park exit on the series of changeable-message signs led to the presentation of conflicting messages to some motorists, thus resulting in erratic driving behavior (cutting across the exit gore). In Experiment 2, the treatment evaluated the use of a phased method of switching the designated theme park exit to eliminate the delivery of conflicting messages. The new method for switching the designated theme park exit was not associated with an increase in motorists cutting across the exit gore.

DESCRIPTORS: motor vehicle conflicts, prompts, conflicting prompts, crashes, alternating treatments design

In 1998 the Florida Department of Transportation was asked by the Federal Highway Administration to evaluate the safety impact of the use of changeable-message signs that functioned as freeway guide signs on Interstate 4 to assign traffic to Universal Theme Park via the International Drive exit or the Kirkman Road exit based on traffic congestion to move theme park traffic more efficiently. Earlier evaluations examined the conspicuity and motorist acceptance of these signs using survey methodology. These data indicated that most motorists noticed the signs and, of those

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respondents who noticed the signs, large percentages saw the attraction of their choice on the signs and selected the correct exit.

Initial observations to determine if there were any negative safety effects were made immediately after each sign became operational. Staff at the Regional Traffic Management Center monitored these sites using cameras placed at sign and exit sites and did not observe problematic changes in driving (e.g., erratic maneuvers, sudden braking, etc.) following the introduction of the signs. They also did not observe any change in vehicle speeds after the signs were implemented. Although these casual observational methods would be adequate for discriminating a sudden extreme reduction in safety, relatively small changes would not be apparent without the use of more systematic data-collection procedures.

One reason why important decreases in safety might not be noted by casual observation techniques is that serious conflicts and crashes normally occur at relatively low rates. Even if operational changes produced a four- or five-fold increase in these variables, it might not be readily apparent to someone who is watching monitors while carrying out other duties.

An analysis of crashes per month between January 1995 and December 1999 at the International Drive exit to Interstate 4 showed that the crash rate averaged 0.16 per month prior to the introduction of the changeable-message signs. Following the introduction of the new signs, the crash rate increased to 0.8 crashes per month. This represents a five-fold increase in crash frequency, an increase that is significant ($t = -4.1$, $p = .0007$), and thus suggests that changing the designated exit for Universal Theme Park may have been responsible. Crashes at two nearby exits (the preceding exit off Interstate 4 at Sandlake Road and the subsequent exit off Interstate 4 at Kirkman Road), which did not have conflicting messages on their exit guide signs, did not show a significant change in crash frequency. The mean number of crashes per month at the Kirkman Road exit averaged 0.605 for the period before the changeable-message signs were installed and 0.267 after the signs were installed. At the Sandlake Road exit, crashes averaged 0.535 before the signs were installed and 0.267 after the signs were installed. The fact that decreases in accidents occurred at these two exits over the same period controls for traffic flow as a functional variable because flow was presumably consistent across the three exits.

A close examination of the crash locations indicated that all of the crashes at the International Drive exit to Interstate 4 occurred adjacent to the exit gore (the exit gore is the crosshatched area at the exit that the driver should not cross). This finding suggested that some aspect of the procedure used to change the messages might have resulted in erratic driver behavior in the vicinity of the exit gore.

Replication that uses within-subject research designs is one way to analyze the effects of specific traffic safety treatments. These designs have the advantage of not requiring a control site. The alternating treatments design is an effective way of comparing the effects and side effects of two different treatments (Hersen & Barlow, 1976; Van Houten & Hall, 2001). An alternating treatments design was employed to assess the efficacy and safety of the system used to divert traffic between two exits on Interstate 4.

One purpose of Experiment 1 was to determine the efficacy of the changeable-message signs as a guide to divert traffic based on exit ramp volumes. The second purpose of Experiment 1 was to assess the safety effects of this procedure by carefully examining driver behavior in the vicinity of the exit gore. The purpose of Experiment 2 was to implement a treatment to remedy problems identified in Experiment 1.

EXPERIMENT 1

Method

How the changeable-message signs were switched. The changeable-message signs allowed

controllers to route travelers by the most efficient route. When controllers saw eastbound traffic build up on the exit ramp for the International Drive exit (this exit is normally the most direct route to Universal Theme Park), they introduced a 10-s dark phase during which neither the International Drive exit nor the Kirkman Road exit were designated as the appropriate exit for Universal Theme Park. After the 10-s dark phase had elapsed, the Kirkman Drive exit was designated as the new Universal Theme Park exit on all three signs. When traffic declined, controllers used the same procedure in reverse to reroute traffic back to the International Drive exit. The protocol for changing the designated exit from International Drive to Kirkman Road is represented in Figure 1. During Plan A (left), the word ''Universal'' (which designates the correct exit for Universal Studios) appeared on all the International Drive changeable-message signs. During Plan B (right), the word ''Universal'' appeared on all the Kirkman Road changeable-message signs. The plan at the bottom shows that the word ''Universal'' did not appear on any of the signs for the first 10 s preceding the change and switched to the Kirkman Road signs after 10 s had elapsed. The same procedure was followed in reverse for changing the designated exit from Kirkman Road to International Drive.

Preliminary analysis. Videotaped data, collected along the system, indicated that conflicts occurred specifically at the International Drive exit. This exit is the main choice for tourists traveling to Universal Theme Park in an eastbound direction on Interstate 4 because the International Drive exit and the next exit at Kirkman Road both route traffic to Universal Theme Park. Confusion resulting from conflicting messages could lead to erratic behavior at the International Drive exit but not the Kirkman Road exit because travelers who did not take the International Drive exit no longer have a choice of exits. Because vehicles traveling at the speed limit took 15 s to progress from the first sign to the second sign and an additional 38 s to get to the final sign located near the International Drive exit, the sign-change protocol allowed drivers to see one exit designated as the correct exit for Universal Theme Park at one or both of the first series of signs and the other exit designated as the correct exit for Universal Theme Park on the last sign at the International Drive exit located adjacent to the start of the exit gore. This set up a conflict that might be expected to cause drivers (most of whom were tourists) to engage in erratic maneuvers to get into or out of the exit lane for the International Drive exit. A last-minute lane change across the exit gore could easily lead to a crash with vehicles traveling in the through lanes, because drivers could reenter the lane or enter the exit ramp at an oblique angle.

Participants and setting. Motorists using Interstate 4 served as participants in this study. Drivers' behavior was scored by observers from videotapes produced by the state's Interstate 4 Surveillance and Motorist Information System staff. Two exit signs were located in advance of Exits 30A (International Drive) and 30B (Kirkman Road), a third exit sign was located at Exit 30A adjacent to the start of the exit gore, and a fourth sign was located 375 ft before the start of the exit gore for Exit 30B. The first exit sign was located 1 mile before Exit 30A. The second sign was located 0.75 mile before Exit 30A. The third sign at Exit 30A was located adjacent to the marked exit gore. The final sign for Exit 30B was located at the start of the exit taper. The diagram for the series of signs is presented in Figure 2.

Observational measures. Observers scored videotapes for gore conflicts at the exit to International Drive. Diversion of traffic was scored by counting the number of vehicles taking the International Drive exit or the Kirkman Road exit and calculating the percentage using the International Drive exit when it was the designated exit and when it was not the designated exit. Data were scored from videotapes, which

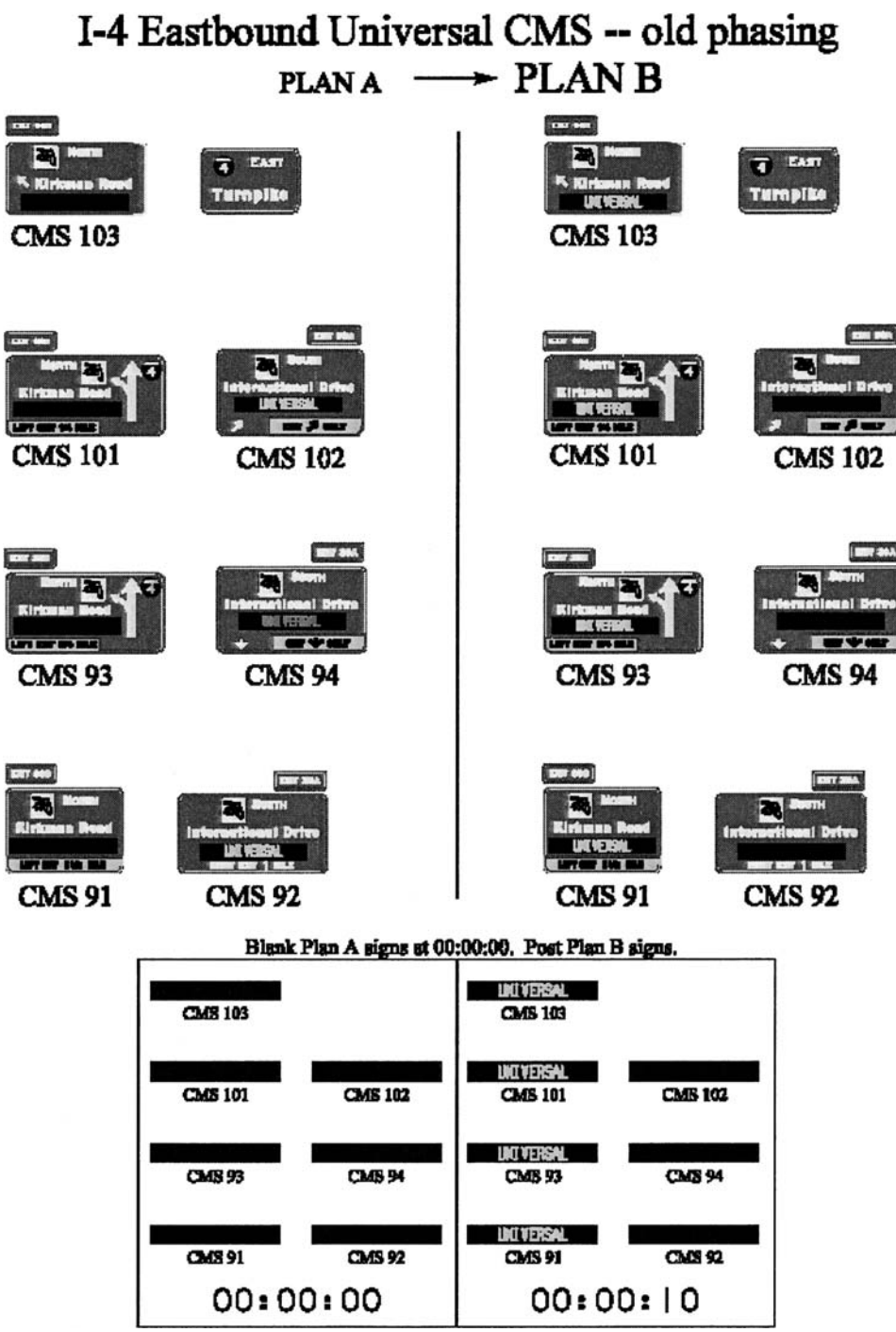

Figure 1. A diagram of the sign-change protocol switching the Universal Theme Park exit from International Drive to Kirkman Road. CMS = changeable-message sign; the following numbers are designation numbers for each sign.

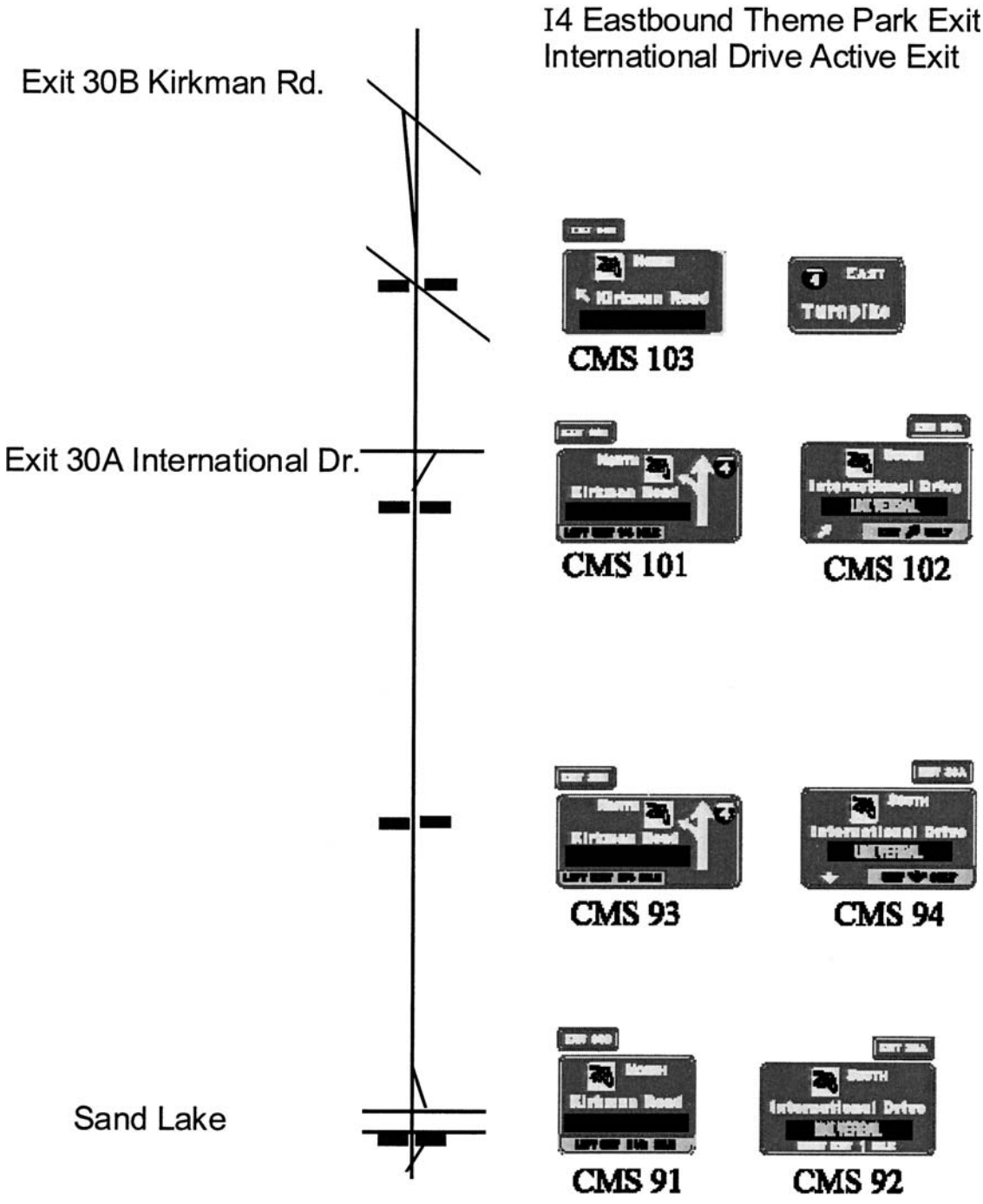

Figure 2. A diagram of Interstate 4 showing the exits and the changeable-message signs.

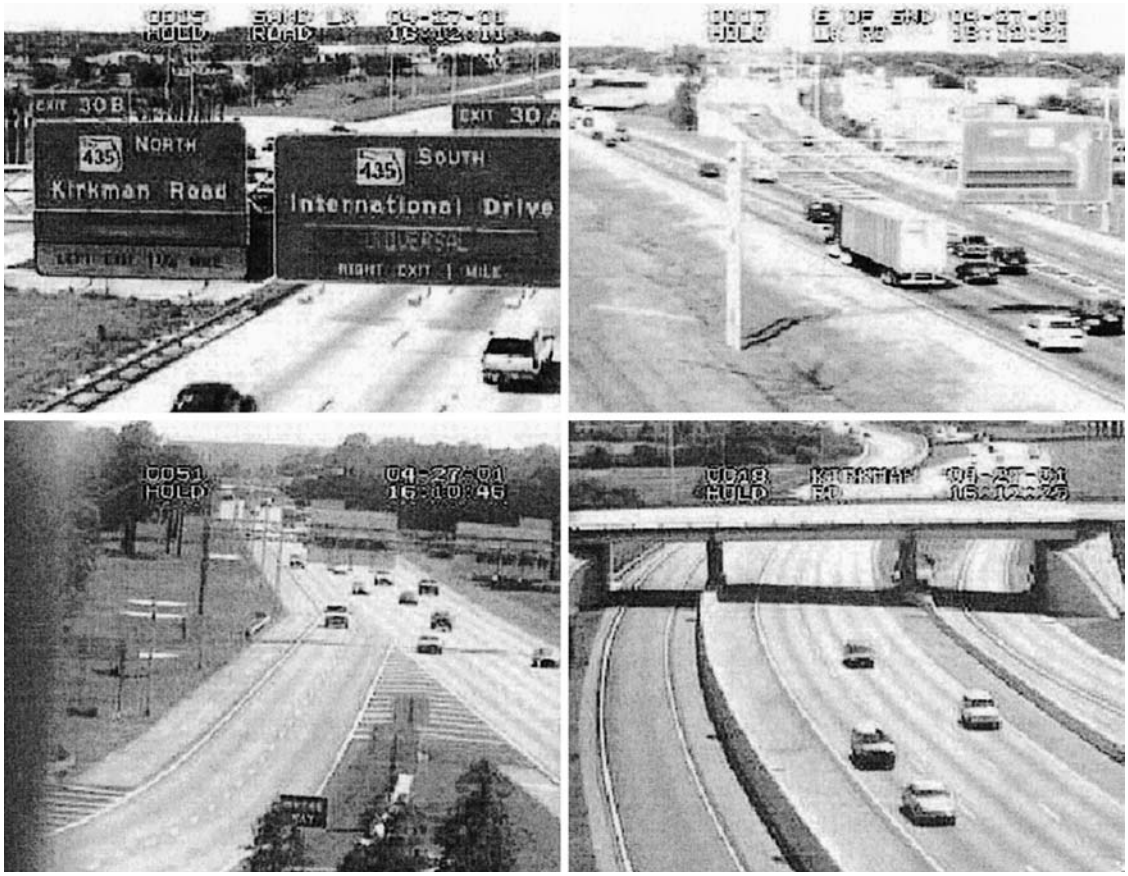

Figure 3. The split screen used to score conflicts and the percentage of vehicles using the International Drive exit.

showed four simultaneous views of traffic on Interstate 4 (Figure 3). Starting with the upper left frame and moving in a clockwise direction, the first frame shows the two signs near the Sand Lake exit 1 mile before the International Drive exit. This view allowed scorers to verify the sign-change protocol and code the start of all sign changes. The next frame shows a side and rear view of the International Drive exit. The next frame shows the Kirkman Road exit looking west. The final frame shows the International Drive exit looking west. This frame afforded the best view of gore conflicts at the International Drive exit.

Gore conflicts were defined as vehicles crossing the exit gore area either to enter the International Drive exit or to reenter Interstate 4 after entering the International Drive exit. This type of conflict is serious because vehicles entering or exiting a high-speed roadway at an oblique angle are at high risk of a crash. To be scored as a gore conflict, the vehicle's tires had to intersect both sides of the gore. This type of conflict was easy to score because one camera was located on a pole at the top of the interchange and could pan down the exit to show the gore area. Examples of gore conflicts are shown in Figure 4. Gore conflicts could be scored as either toward or away from the designated or active exit shown on the exit signs at the International Drive exit. The active exit was defined as the exit designated as the exit for Universal Theme Park.

Diversion of traffic was scored by counting the number of vehicles passing a landmark at each exit using a hand counter. The percentage

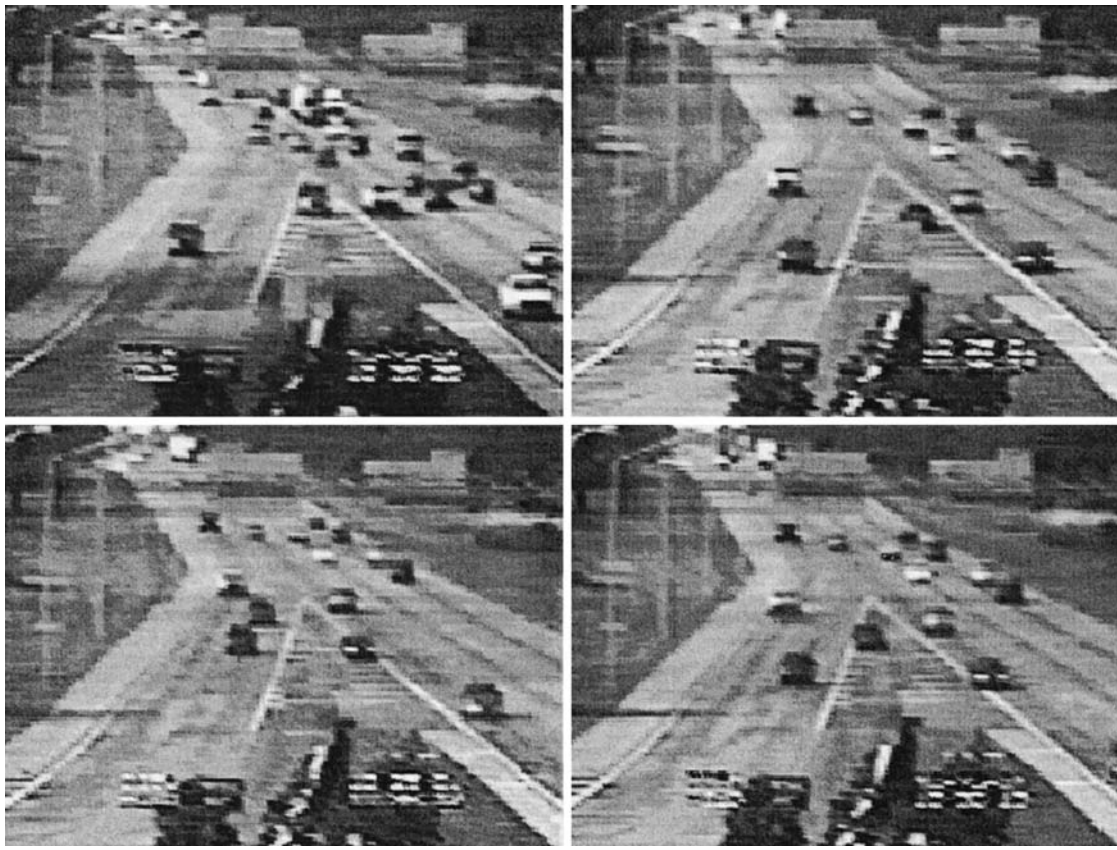

Figure 4. Examples of gore conflicts scored by the observers.

of drivers taking the International Drive exit was then calculated for each data sample by dividing the number of vehicles taking this exit by the number of vehicles taking this exit plus the number of vehicles taking the Kirkman Road exit.

Experimental design. An alternating treatments design was used to document the efficacy and safety impact of the changeable-message signs. Baseline or steady-state data were measured when all the guide signs specified Exit 30A as the exit for Universal Theme Park. These data allowed the researchers to calculate the baseline rate of gore conflicts and the percentage of vehicles using Exit 30A before the signs were changed. Data were then calculated during the 10-s dark phase when none of the message signs were designated as the Universal Theme Park exit. Next, data were scored for the 1st minute after the exit signs were changed. A 1-min interval was selected because after a minute had elapsed all vehicles present when the signs changed should have cleared the system, thus beginning a new steady-state condition with the Kirkman Road exit as the new designated exit for Universal Theme Park. Steady-state data were then collected for Kirkman Road. Next, data were scored during the new 10-s dark phase and during the 1st minute after International Drive again became the designated exit. This procedure was repeated 175 times to obtain a large database from which to evaluate sign transitions. All data were collected during busy times when traffic was heavy at the International Drive exit (typically morning hours or at times when

special events were scheduled at Universal Theme Park).

Interobserver agreement. Two observers independently scored the same videotapes, and their spreadsheets were compared to determine whether the definitions and training were adequate to allow them to score gore conflicts and driver counts. Interobserver agreement was computed by dividing the number of times both observers agreed on the occurrence of each behavior by the number of times they agreed and disagreed on the occurrence of each behavior. Interobserver agreement on gore conflicts averaged 98% (range, 91% to 100%). Interobserver agreement on vehicle counts averaged 99.7% (range, 98% to 100%).

Results

Observational data. The percentage of drivers taking the International Drive exit before and after each block of five transitions is presented in Figure 5 (top). These data show that a higher percentage of drivers used the International Drive exit when it was designated as the Universal Theme Park exit than when the Kirkman Road exit was designated as the Universal Theme Park exit. Thus, the sign was effective in diverting traffic from one exit to the other.

On average, 70% of motorists used the International Drive exit when it was specified at the Universal Theme Park exit, and 47% used this exit when the Kirkman Road exit was specified as the Universal Theme Park exit. The rate of gore conflicts toward the exit designated as the Universal Theme Park exit during the steady-state or baseline condition and during the 1st minute after a new exit was designated on the signs for each block of five transitions is also presented in Figure 5 (bottom). The rate of gore conflicts increased from 0.12 to 0.37 per minute during the minute after the new exit was designated as the Universal Theme Park exit. This represents a three-fold increase in gore conflicts. Although these data show some variability, conflicts were higher after the change in the designated exit for 16 of 18 sessions, tied for one session, and lower during the steady-state condition for only one session.

Discussion

The results of Experiment 1 show that switching the designated exit on the changeable-message signs led to an increase in gore conflicts at the International Drive exit; this is consistent with the increase in crashes noted in the area adjacent to the exit gore following the introduction of the changeable-message signs. This increase is consistent with a behavioral analysis of the method used for changing the signs, which involved a 10-s dark phase prior to switching all three signs to designate a different exit for Universal Theme Park. This method ensured that some drivers received conflicting exit prompts at the International Drive exit. Because Exit 30A was a right exit and Exit 30B was a left exit, it followed that impulsive drivers could respond to this message by making a sudden lane change that involved crossing the exit gore at an oblique angle. The method used to change the exit designated for Universal Theme Park is likely responsible for the increase in crash frequency. One way to eliminate the possibility of conflicting messages is to change the guide signs in a phased manner and to increase the dark phase on the exit at International Drive to allow all motorists who saw the sign showing the old exit on one or both of the previous two guide signs to have already passed the third guide sign located at this exit before the new exit sign was illuminated. The purpose of Experiment 2 was to evaluate the efficacy and safety of a second sign-change protocol for the International Drive and Kirkman Road exits that was designed to eliminate conflicting messages.

EXPERIMENT 2

Method

How the changeable-message signs were switched. In Experiment 2 the signs were changed to divert traffic from International

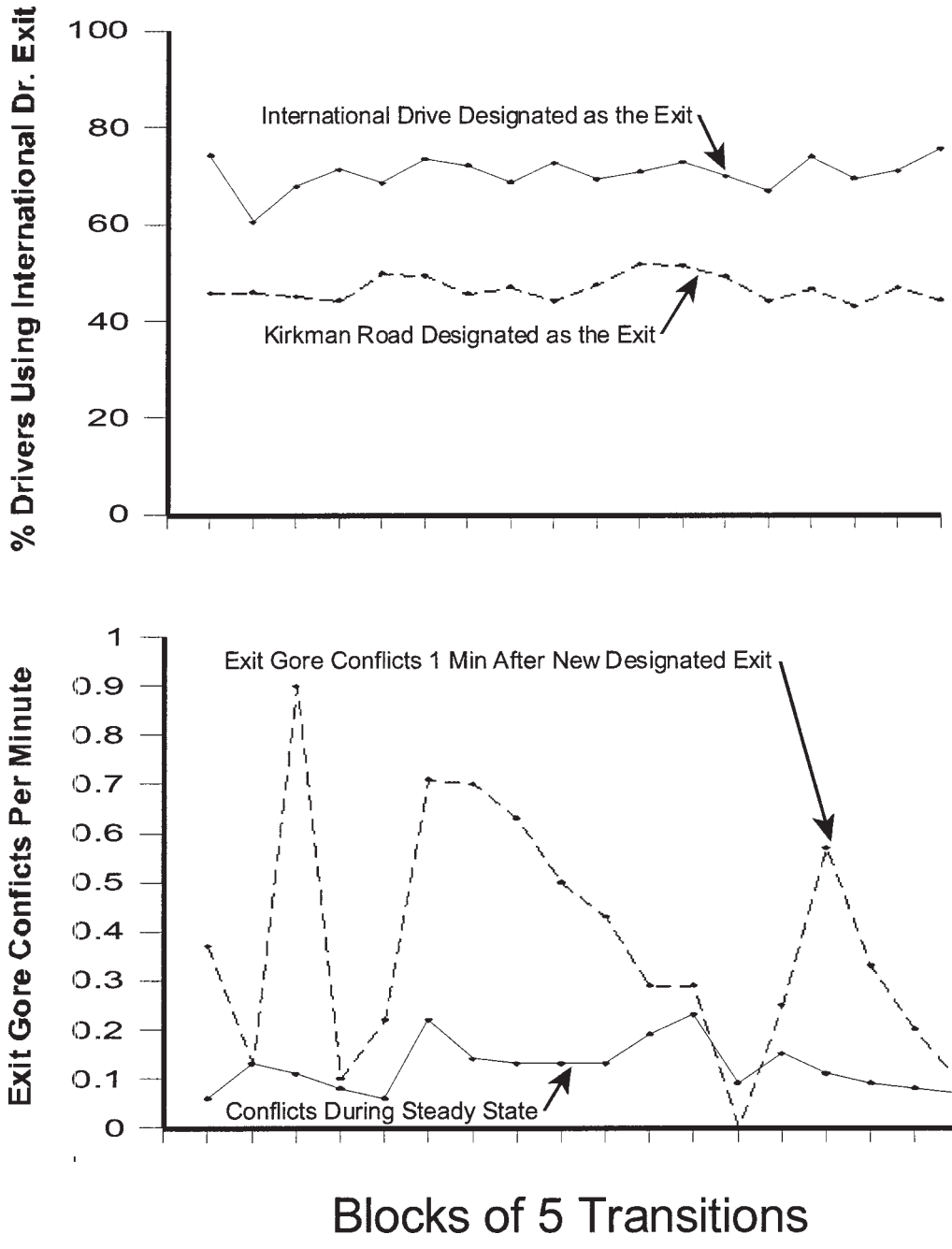

Figure 5. The upper frames show the percentage of drivers taking the International Drive exit before and after each block of five transitions, and the lower frame shows the number of conflicts per minute during the steady-state condition and during the 1st minute after the designated exit was changed for each block of five transitions.

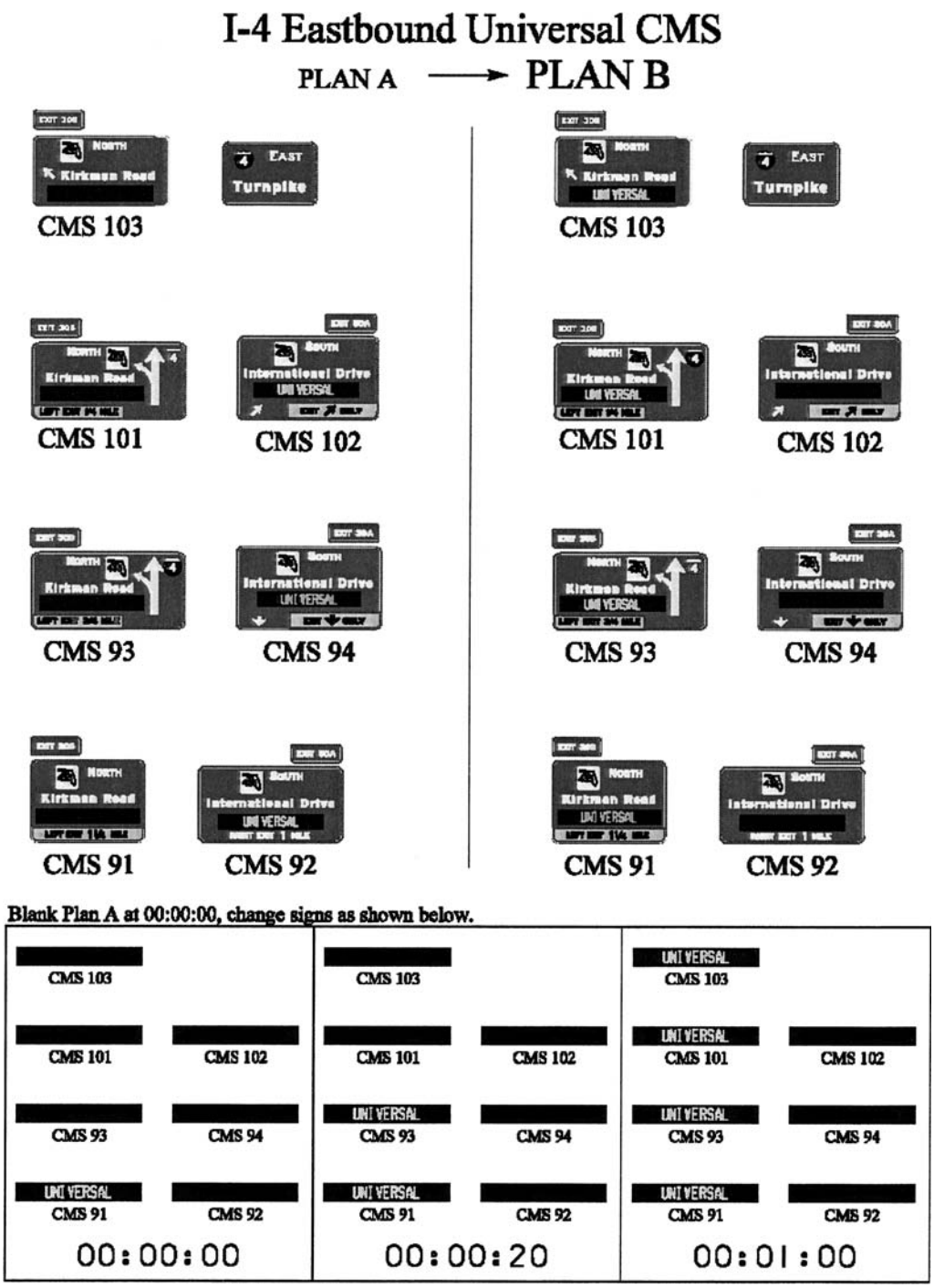

Figure 6. A diagram of the phased sign-change protocol employed in Experiment 2 for switching the Universal Theme Park exit from International Drive to Kirkman Road.

Drive to Kirkman Road using the phased sign-change method illustrated in Figure 6. The first sign at the Sand Lake Exit was immediately switched from the old exit to the new exit, and the second two signs were placed in the dark phase. After 20 s, the new exit appeared on the second sign. After 1 min had elapsed, the sign at the International Drive exit indicated the new exit. The same procedure was used to change the designated exit from Kirkman Road to International Drive.

Participants and setting. Participants and setting were the same as described for Experiment 1.

Observational measures. Observers scored videotapes for gore conflicts and redirection of traffic at the exit to International Drive in the same way as described in Experiment 1.

Experimental design. The experimental design was identical to that used in the previous experiment.

Interobserver agreement. Interobserver agreement data were obtained in the same manner as described in Experiment 1. Interobserver agreement on gore conflicts was 100%. Interobserver agreement on vehicle counts was 100%.

Observational data. The percentage of drivers taking the International Drive exit and the percentage of drivers taking the Kirkman Road exit before and after each block of five transitions closely replicated the results of Experiment 1, showing that a higher percentage of drivers used the International Drive exit when it was designated as the Universal Theme Park exit than when the Kirkman Road exit was designated as the Universal Theme Park exit. On average 64% of motorists used the International Drive exit when it was specified as the Universal Theme Park exit, and 42% used this exit when the Kirkman Road Exit was specified as the Universal Theme Park exit.

The rate of gore conflicts toward and away from the exit designated on the International Drive exit sign is shown in Figure 7 for the steady-state or baseline condition, during the dark phase, and during the 1st minute after the new exits appeared on the signs for Experiments 1 and 2. In Experiment 1, steady-state conflicts toward the exit that was designated as the Universal Theme Park exit averaged 0.118, and gore conflicts toward the exit that was not designated as the Universal Theme Park exit averaged 0.081. Conflict rate during the dark phase was 1.4. Because there was not a designated exit during the dark phase, some conflicts were toward the International Drive exit and some were away from the International Drive exit. To compare dark-phase conflicts with diverted-phase conflicts, dark-phase conflicts were divided by two, yielding an average of 0.07. Gore conflicts toward the designated exit for the Universal Theme Park increased during the minute following the change to 0.358. This represents a three-fold increase in gore conflicts.

In Experiment 2 (Figure 7, bottom), there was little variation in gore conflicts across conditions involving the steady state, the dark phase, and the 1st minute after the exit had been designated on the changeable-message sign at the International Drive exit. Gore conflicts toward the designated exit averaged 0.117 during the steady-state condition and 0.110 toward the designated exit during the 1-min period following the designation of the new exit on the International Drive sign. Gore conflicts toward the inactive exit averaged 0.083 during the steady-state condition and 0.120 following the designation of the new exit.

Discussion

The results of Experiment 2 demonstrated that the introduction of the new procedure for switching the changeable-message signs reduced the increase in conflicts associated with changing the designated exit. Therefore this procedure appears to be an effective method for improving the safety of drivers being diverted by changing signs at the International Drive exit. This new sign-change protocol is currently in place.

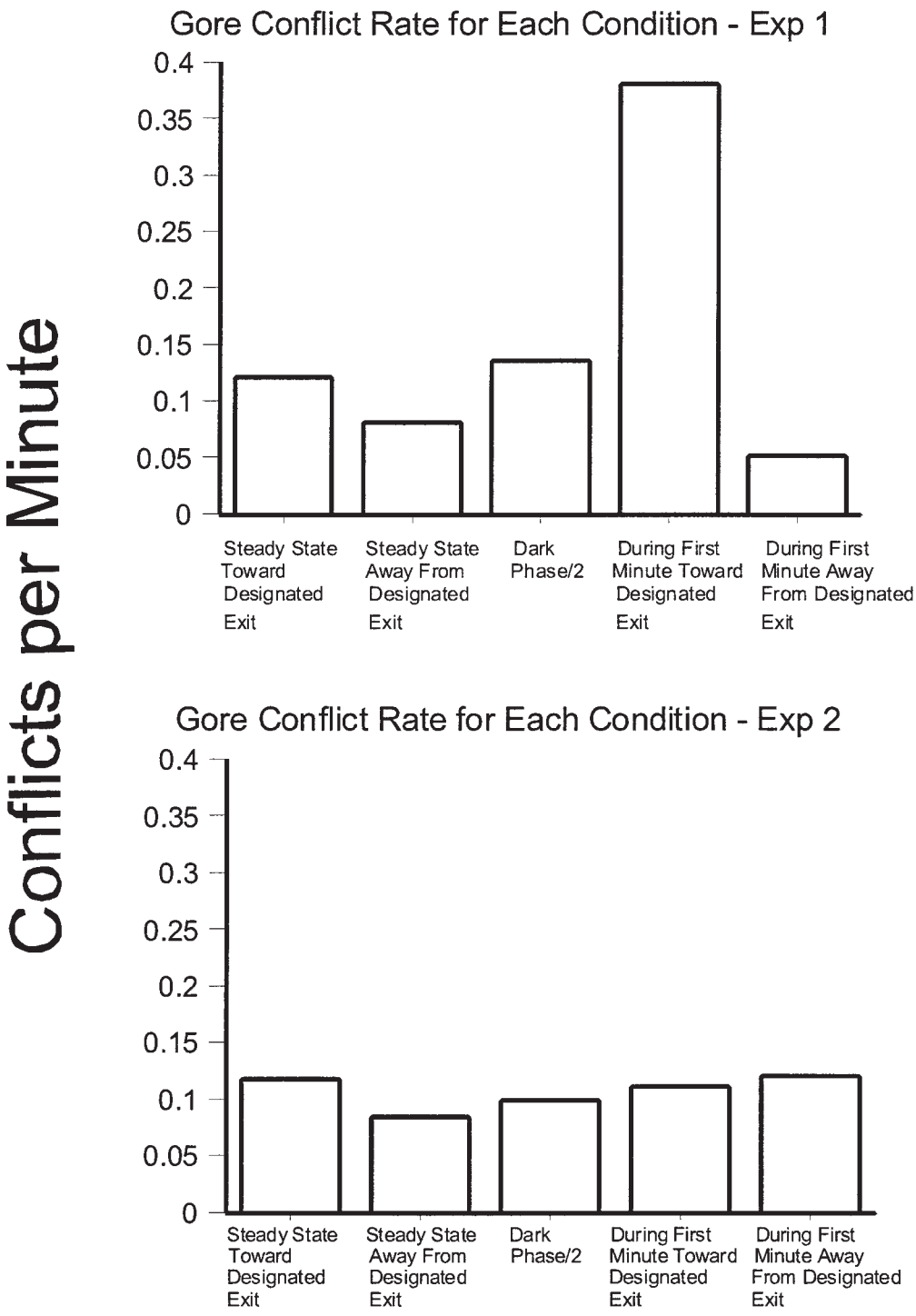

Figure 7. The upper frame shows the rate of gore conflicts either toward or away from the designated exit during the steady-state or baseline condition, the dark phase, and the 1st minute after the new exits appeared on the signs during Experiment 1. The bottom frame shows the rate of gore conflicts either toward or away from the designated exit during the steady-state or baseline condition, the dark phase, and the 1st minute after the new exits appeared on the signs during Experiment 2. Note that the dark phase for the International Drive exit was longer during this condition.

GENERAL DISCUSSION

The results of the first experiment indicated that the method used to switch the changeable-message signs between the International Drive exit and the Kirkman Road exit based on traffic flows led to an increase in gore conflicts that were associated with an increase in the frequency of crashes. The method used to change the signs involved presenting some drivers with a conflicting message on the exit to take to reach Universal Theme Park. Because the message that conflicted with preceding messages was presented on a sign located at the start of the exit gore and involved a conflict between a left and a right exit, there was an increase in gore intrusions and sudden lane changes.

In the second experiment the method used to switch the signs was altered to prevent the delivery of conflicting messages when the theme park exit was switched. This change was not associated with an increase in conflicts at the exit. In both experiments changing the designated exit for Universal Theme Park was associated with a diversion of traffic to the newly designated exit.

These data show that changeable-message signs can be effective in redistributing tourist traffic from one exit to another. They also show that under some circumstances changing the active exit may lead to an increase in erratic driving behavior. It is often recommended that prompts are most effective when they are presented immediately prior to the behavior to be prompted (Van Houten, 1998). However, prompting two incompatible driver behaviors in close temporal proximity can lead to erratic driving behavior. Common sense, the logic of traffic safety, the science on information prompting, and the results of this study all suggest that when multiple close-proximity prompts are used to inform drivers, potential conflicts between prompts should be eliminated. The results of this study not only support that assertion but also showcase the alternating treatments design as an effective means of establishing that support experimentally. More generally, the methods and the results highlight the benefits of applied behavior analysis when used to promote traffic safety through effective traffic engineering.

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